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LOST AND FOUND: THE DAMPED Lyα ABSORBERS IN THE QSO OI 363[1]

JUDITH G. COHEN
Palomar Observatory, Mail Stop 105-24, California Institute of Technology, Pasadena, CA 91125; jlc@astro.caltech.edu
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ABSTRACT

The galaxy giving rise to the damped Lyα absorbing system with $z = 0.221$ in the QSO OI 363 has been found. A galaxy that is probably associated with the second damped Lyα absorber (DLA) in the same QSO ($z = 0.0912$) has also been found. Neither galaxy is very luminous, and neither galaxy shows signs of extensive current star formation, a massive disk, or lots of gas. The impact parameters for both galaxies with respect to the QSO are reasonable. If most DLAs arise in such low-luminosity galaxies, it will be difficult to pick out the correct source galaxy for DLA systems at high redshift, given the large projected areal density on the sky of faint galaxies around distant QSOs.

Key words: galaxies: halos — quasars: absorption lines — quasars: individual (OI 363)

1. INTRODUCTION

A long series of investigations reviewed by Weymann, Carswell, & Smith (1981; for a current update, see Bergeron & Boissé 1991, Steidel et al. 1997, and Churchill et al. 1999) has established that when the H I column density is sufficiently large [N(H I) $> 10^{15}$ atoms cm^{-2}], Lyα absorption seen in the spectra of QSOs is often accompanied by absorption in the C IV doublet at 1550 Å. At somewhat higher column densities [N(H I) $> 10^{17}$ atoms cm^{-2}], C II, Si II, Al II, Fe II, and Mg II are often detected. Furthermore, the origin of the low-ionization absorbing gas can usually be identified as a luminous galaxy with a redshift matching that of the absorbing gas and an impact parameter of $\lesssim 150$ h^{-1} kpc with respect to the QSO. Chen et al. (1998) present recent results on identifying the galaxies that give rise to the lower column density Lyα forest absorption. Such studies are a key way of probing gas in the outer regions of galaxies.

Damped Lyα absorbers (DLAs) are those rare cases with the highest H I column densities, N(H I) $> 10^{20}$ atoms cm^{-2}. It is thus somewhat puzzling that one of the nearest DLAs, the system with $z = 0.0912$ seen in the spectrum of the QSO OI 363, remains unidentified. This DLA was discovered by Rao & Turnshek (1998, hereafter RT) during a large survey program (described in Rao & Turnshek 2000) to scrutinize *HST* spectra of QSOs taken in the UV. However, they were unable to identify the galaxy producing the absorption. By chance, there is a second DLA in the spectrum of this QSO, at $z = 0.2212$, and they were also unable to establish the origin of this DLA. The H I from these two systems has been detected in absorption at 21 cm by Lane et al. (1998) and by Chengalur & Kanekar (1999).

RT presented a deep image of the field of this QSO and obtained a spectrum of the brightest galaxy within 30″ of the QSO (galaxy G11, using their identifications; see their Fig. 4), which shows pronounced spiral arms. Galaxy G11 turned out to be a foreground object at $z = 0.06$ not associated with either of the DLA systems. The most likely remaining candidate for the source of the DLA, identified in the deep imaging survey of Le Brun et al. (1993), was too faint for them to obtain a spectrum. They state that, with the elimination of G11, there is no candidate galaxy bright enough to produce these two DLA systems and that this indicates an inconsistency with the standard model developed by Prochaska & Wolfe (1998) for DLAs arising in large H I disks of galaxies.

2. NEW SPECTROSCOPY IN THIS FIELD

I have obtained spectra of the two next brightest candidates within 30″ of the QSO, with the hope of identifying the absorbing galaxy in each of the two low-z DLA systems in OI 363. The properties of the four brightest galaxies near this QSO are listed in Table 1. A more complete census of the galaxies near OI 363 can be found in RT.

I have established that the DLA system with $z = 0.2212$ originates in galaxy G1, which is only 6″ from the QSO. This is the galaxy suggested as the possible DLA host by Le Brun et al. (1993). The measured redshift of this galaxy is $z = 0.221$, based on a 1500 s exposure taken on 2000 March 6 with the Low Resolution Imaging Spectrograph (LRIS; Oke et al. 1995) at the Keck Observatory using a 1.″5 slit with a 300 g mm^{-1} grating (spectral resolution 15 Å). The luminosity of G1 is $M_R = -19.3$ ($L_R^*/7$).[2] The impact parameter with respect to the QSO is 13 h^{-1} kpc.

The spectrum of G1 is shown in Figure 1. Absorption in the H + K doublet of Ca II is strong, and a pronounced 4000 Å break is seen, as well as the G band of CH and the ultraviolet CN band. No emission lines were detected, with an upper limit to the equivalent width for the 5007 Å [O III] line of 5 Å and for Hα of 10 Å. The signal-to-noise ratio (SNR) in the continuum per spectral resolution element is 45 at about 4885 Å (rest frame 3990 Å) and ~ 37 at rest frame 3790 Å, i.e., just above and below the H + K doublet.

The origin of the absorption for the DLA system with $z = 0.0912$ is still unclear. Galaxy G10 is probably associated with this gas in some way but is not directly the source. This galaxy, which RT describe as an "early-type galaxy," is 28″ from the QSO. G10 is somewhat bluer in $B-R$ than G11 (Monet et al. 1999). The redshift of G10 is $z = 0.106$. With this redshift, G10 has an impact parameter of ~ 35 h^{-1} kpc and a luminosity of $M_R = -18.2$ ($L_R^*/14$). Its spectrum (a 1000 s exposure with the same instrumental configuration as for G1) is also shown in Figure 1. It appears

[1] Based in large part on observations obtained at the W. M. Keck Observatory, which is operated jointly by the California Institute of Technology and the University of California.

[2] We adopt $H_0 = 70$ km s^{-1} Mpc^{-1} and $\Omega_M = 0.3$.

TABLE 1
PROPERTIES OF THE FOUR BRIGHTEST GALAXIES NEAR THE QSO OI 363

ID	R[a] (mag)	z	M_R (mag)	$\Delta(\theta)$[a] (arcsec)
G11......	17.1	0.06[a]	−20.3	31
G10......	19.8	0.106	−18.9	28
G1.......	20.8	0.221	−19.6	6
G6.......	22.0	...	...	16

[a] From Rao & Turnshek 1998.

similar to that of G1, but the 3968 Å line is stronger relative to that at 3933 Å than in galaxy G1. The G band of CH appears to be present in the spectrum of G10. The [O II] emission line at 3727 Å is beyond the blue end of the spectrum; the range is 4200 to 8900 Å. The SNR here in the continuum per spectral resolution element is between 35 and 40 at wavelengths just below and just above the H + K doublet of Ca II. There is a possible detection of Hα with an equivalent width of ∼3 Å. The velocity difference between G10 and the DLA itself is uncomfortably large (∼4000 km s^{-1}) and therefore G10 itself cannot be the origin of the DLA absorption.

Thus the three brightest galaxies within 30″ of the QSO, G1, G10, and G11, have now been observed spectroscopically, and none appears to be the source for this DLA gas. The next brightest galaxy within this area, assuming that no mistake was made by RT in separating stars from galaxies, is more than 1 mag fainter than G1, which is the faintest of the three already observed spectroscopically. (The field is at a rather low Galactic latitude [$b = 23^\circ.6$], so there are many stars in this magnitude range as well.)

Perhaps G10 is a member of a cluster and one of the other galaxies in that group is the actual host for the absorbing gas. Hopefully, planned future observations of some of the fainter galaxies nearer the QSO than G10 will reveal the host for this DLA soon, but the upper limit on its luminosity is now constrained to be $L_R^*/30$.

3. DISCUSSION

As emphasized by Steidel, Dickinson, & Persson (1994), all normal field galaxies can give rise to QSO absorption lines, albeit generally of lower total column density than those characteristic of DLAs. Steidel et al. (1997) find that in the regime $z \sim 0.5$ any galaxy over a wide range of morphological types, from late spirals to S0's, with $L > L^*/10$ can produce Mg II absorption and an associated Lyα forest line. The H I column densities required for a DLA system are, however, several orders of magnitude higher.

Identifications are available for a few other low-z DLAs. Lanzetta et al. (1997) have established that the galaxy responsible for the $z = 0.1638$ absorption in the spectrum of QSO 0850+4400 is a moderate luminosity ($L_B^*/2.3$) S0 galaxy. However, the H I column density for this system [$\log N(\text{H I}) = 19.81$] is just below the cutoff normally adopted for DLAs. The closest known DLA, studied by Miller, Knezek, & Bregman (1999), arises in the outer part of NGC 4203, with Ton 1480 as the background QSO. NGC 4203 is an isolated E3 galaxy (de Vaucouleurs, de Vaucouleurs, & Corwin 1976) with $M_B \approx -19.2$, which corresponds roughly to $L_B^*/3$.

Even though the sample is small, it is clear that gas-rich galaxies with extensive current star formation and luminosities greater than $L^*/3$ are not the dominant origins of the low-z DLA systems. Galaxies of moderate luminosity without obvious signs of high gas content from their optical morphology or spectra appear to give rise to DLA systems when there is a background QSO with a suitable impact parameter.

A possible origin for DLA gas is low-luminosity, gas-rich dwarf galaxies such as the Local Group member NGC 6822, which has a large H I halo with a mass of about $1.5 \times 10^8\ M_\odot$ (Roberts 1972) in spite of its low luminosity of $M_V \sim -16.0$. However, the admittedly small sample of known low-z DLA galaxies are not gas-rich dwarfs.

Many intermediate-redshift DLA candidates are identified from *HST* imaging surveys, with few spectroscopic confirmations. Le Brun et al. (1997) and Steidel et al. (1995) suggest that the most probable DLA candidates are galaxies of moderate luminosity. Steidel et al. (1995) find that the probable identification for the DLA with $z = 0.8596$ along the line of sight to PKS 0454+0356 has $M_B = -18.7$, corresponding to $L_B^*/4$, ignoring any evolution in luminosity of L_B^* with redshift.

The suggestion that high-redshift DLAs arise in dwarf galaxies has been made by York et al. (1986), and more recently by Matteucci, Molaro, & Vladilo (1997), while Jimenez, Bowen, & Matteucci (1999) have suggested low surface brightness galaxies as the culprits. On the other hand, McDonald & Miralda-Escudé (1999) and Haehnelt, Steinmetz, & Rauch (1998) view the DLAs at high redshift as resulting from the formation of protogalaxies, and they ascribe the velocity widths to turbulence rather than to ordered motions in normal, rotating galactic disks. Ground-based long-slit spectroscopy at rest-frame Hα and *HST* imaging (see Bunker et al. 1999 and Kulkarni et al. 2000, respectively) demonstrate that suspected sources of DLAs at high redshift appear to have small sizes and low star formation rates.

Thus the Prochaska & Wolfe (1998) model of massive rotating disks does not correspond to the observed properties of most galaxies that give rise to DLA systems at low redshift, and this may also hold true at high redshift.

The fact that low-z DLA systems seem to be identified with low-luminosity galaxies that are neither starbursts nor other gas-rich systems is rather unexpected. It implies that

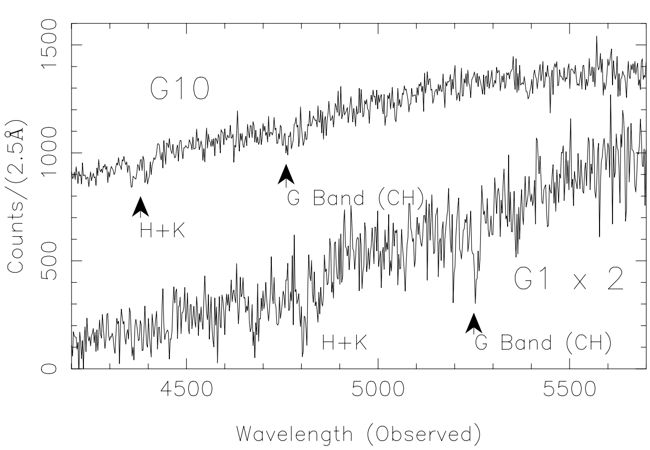

FIG. 1.—LRIS spectra of galaxies G1 and G10 near the QSO OI 363. Vertical axis is counts pixel^{-1}, with two detected electrons producing one count. The spectrum of galaxy G1 has been multiplied by a factor of 2.0 and there is a vertical offset of 800 counts between the two spectra.

searches for the galaxies producing DLA systems at high redshift will be quite difficult, because it will not be easy to determine the right galaxy from the projection of the galaxy luminosity function through a long line of sight. Furthermore, since the majority of field galaxies occur in groups out to at least $z \sim 1.1$ (Cohen et al. 2000), one may misidentify the distant DLA gas with a galaxy that is in fact not its true source but rather some brighter member of the same group or cluster.

Perhaps the selection effects attributed to dust, discussed by Ostriker & Heisler (1984) and applied to DLA systems in particular by Fall & Pei (1993) and most recently by Boissé et al. (1998), are responsible. They suggest that the higher mean extinction within massive galaxies with high dust content and high metallicity limit our ability to detect the background QSOs. Since dust absorption is higher in the UV, another consequence of dust would be a limitation, dependent on z(QSO)$-z$(DLA), in our ability to obtain UV spectra of the background QSOs to find the absorption line systems. Such a selection effect would skew the probability that a galaxy produces a detectable DLA system away from its proper reliance on only the galaxy's gas column density and impact parameter with respect to the QSO. Another consequence of dust might be to bias calculations, based on QSO absorption features, of the contribution of the neutral gas to the cosmological mass density. If low-z DLA systems continue to be identified with low-luminosity galaxies, the selection effects caused by dust may be an important reason why.

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REFERENCES

Bergeron, J., & Boissé, P. 1991, A&A, 243, 344
Boissé, P., Le Brun, V., Bergeron, J., & Deharveng, J.-M. 1998, A&A, 333, 841
Bunker, A. J., Warren, S. J., Clements, D. L., Williger, G. M., & Hewett, P. C. 1999, MNRAS, 309, 875
Chen, H.-W., Lanzetta, K. M., Webb, J. K., & Barcons, X. 1998, ApJ, 498, 77
Chengalur, J. N., & Kanekar, N. 1999, MNRAS, 302, L29
Churchill, C. W., Mellon, R. R., Charlton, J. C., Jannuzi, B. T., Kirhakos, S., Steidel, C. C., & Schneider, D. P. 1999, ApJ, 519, L43
Cohen, J. G., Hogg, D. W., Blandford, R., Cowie, L. L., Hu, E., Songaila, A., Shopbell, P., & Richberg, K. 2000, ApJ, 538, 29
de Vaucouleurs, G., de Vaucouleurs, A., & Corwin, H. G., Jr. 1976, Second Reference Catalogue of Bright Galaxies (Austin: Univ. Texas Press)
Fall, S. M., & Pei, Y. C. 1993, ApJ, 402, 479
Haehnelt, M. G., Steinmetz, M., & Rauch, M. 1998, ApJ, 495, 647
Jimenez, R., Bowen, D. V., & Matteucci, F. 1999, ApJ, 514, L83
Kulkarni, V., Hill, J. M., Schneider, G., Weymann, R. J., Storrie-Lombardi, L. J., Rieke, M. J., Thompson, R. I., & Jannuzi, B. T. 2000, ApJ, 536, 36
Lane, W., Smette, A., Briggs, F., Rao, S., Turnshek, D., & Meylan, G. 1998, AJ, 116, 26
Lanzetta, K. M., et al. 1997, AJ, 114, 1337
Le Brun, V., Bergeron, J., Boissé, P., & Christian, C. 1993, A&A, 279, 33
Le Brun, V., Bergeron, J., Boissé, P., & Deharveng, J. M. 1997, A&A, 321, 733
Matteucci, F., Molaro, P., & Vladilo, G. 1997, A&A, 321, 45
McDonald, P., & Miralda-Escudé, J. 1999, ApJ, 519, 486
Miller, E. D., Knezek, P. M., & Bregman, J. N. 1999, ApJ, 510, L95
Monet, D. G., et al. 1999, USNO-A2.0 (Washington: US Naval Obs.)
Oke, J. B., et al. 1995, PASP, 107, 375
Ostriker, J. P., & Heisler, J. 1984, ApJ, 278, 1
Prochaska, J. X., & Wolfe, A. M. 1998, ApJ, 507, 113
Rao, S. M., & Turnshek, D. A. 1998, ApJ, 500, L115 (RT)
———. 2000, ApJS, 130, 1
Roberts, M. S. 1972, in IAU Symp. 44, External Galaxies and Quasi-Stellar Objects, ed. D. S. Evans, D. Willis, & B. J. Wills (Dordrecht: Reidel), 12
Steidel, C. C., Bowen, D. V., Blades, J. C., & Dickinson, M. 1995, ApJ, 440, L45
Steidel, C. C., Dickinson, M., Meyer, D. M., Adelberger, K. L., & Sembach, K. R. 1997, ApJ, 480, 568
Steidel, C. C., Dickinson, M., & Persson, S. E., 1994, ApJ, 437, L75
Weymann, R. J., Carswell, R. F., & Smith, M. G., 1981, ARA&A, 19, 41
York, D. G., Dopita, M., Green, R., & Bechtold, J. 1986, ApJ, 311, 610